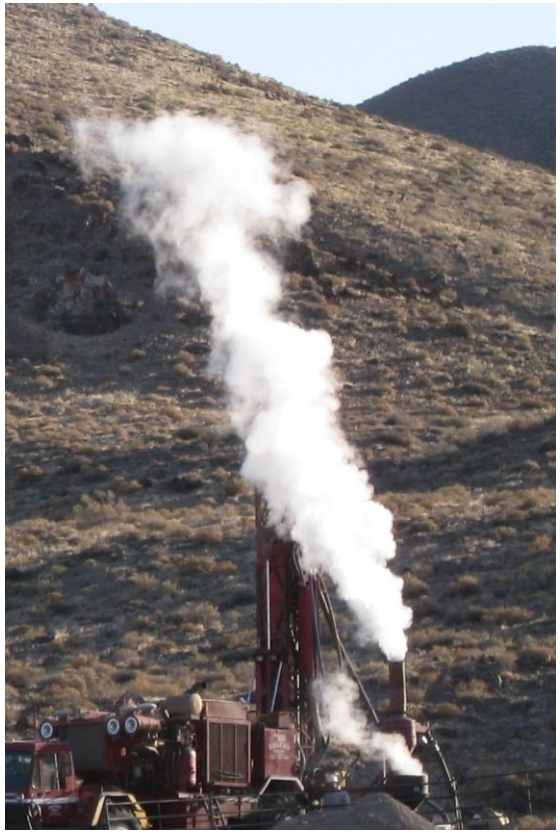

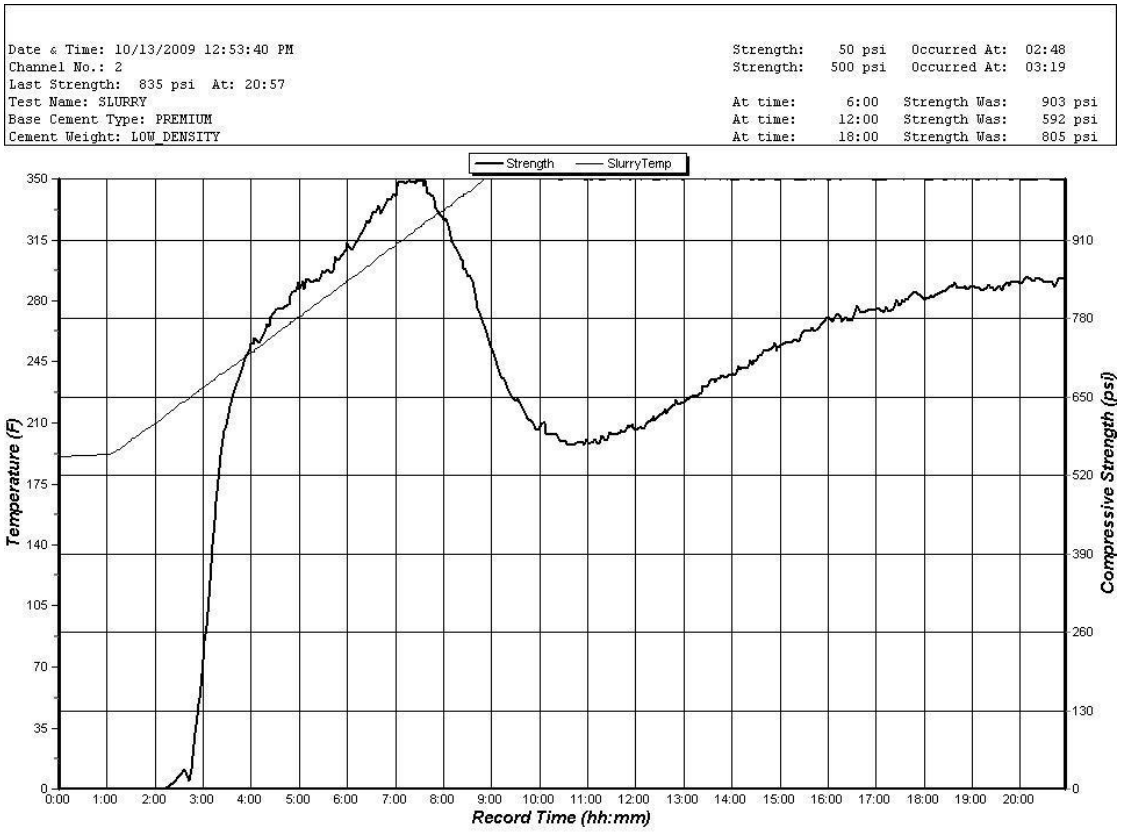

Development of an Improved Cement for Geothermal Wells

June 9, 2011

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Co-Presenter
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Track 2 R&D

Project Overview

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Timeline

Project Budget

- DOE Share $2,154,238
- Awardee Share $ 538,557
- Total Project $2,692,795

FY11 2Q Status

- DOE Share $540,381
- Awardee Share $135,510
- Percent Completed 30%

Relevance/Impact of Research

Project Objective

- Develop a novel, zeolite-containing lightweight, high temperature, high pressure geothermal cement, which will provide operators with an easy to use, flexible cementing system that saves time and simplifies logistics.

Impact of New Cement Development

- Eliminate the requirement to “sterilize” pumping equipment before use.
- Eliminate the need to foam the slurry to achieve lightweight qualities.
- Eliminate incompatibility issues in the selection of retarders and accelerators.
- Provide predictability and minimize the effect of down-hole temperature fluctuation.
- Facilitate the development of geothermal resources in remote locations.

Scientific/Technical Approach

- Build on existing zeolite-containing cement technology for low temperature, weak formation applications.
- Systematic, scientific approach on trial cement blends to consider the variables of:
  - Zeolite type
  - Zeolite particle size
  - Zeolite percentage by weight of cement
  - Additives for thermal stability and resistance to carbonation
  - Effect of cement type (Class H / Class G)
- Clear and concise performance characteristics provide a systematic method for initial screening, second stage development and ultimately for the final stage of cement development.
- This logical progression of scientific study results in five Tasks that lead to realistic project milestones and go / no-go decisions points.

Zeolite Sample Acquisition

- Four different zeolites are being used.
  - Clinoptilolite (California)
  - Clinoptilolite (New Mexico)
  - Chabazite (Arizona)
  - Ferrierite (Nevada)

- One thousand pounds of each zeolite type was collected. To ensure repeatability - sufficient volume for all Screening and Second Stage Cement Development.

- Each sample type was field crushed to a uniform minus US 8 Mesh product.

- Each bulk sample was representatively sampled for XRD / SEM analysis.

Literature Review

- **Well Completion Failure Mechanism**

1. Expansion of casing due to increase in temperature or pressure
   - Plastic deformation of cement
   - Gas migration
2. Cement failure due to increase in temperature generally takes place in the top half of the wellbore
3. Increase in stresses
   - Shrinkage of cement
   - Pressure changes
4. Cement failure due to pressure generally takes place in the bottom half of the wellbore

Literature Review Continued

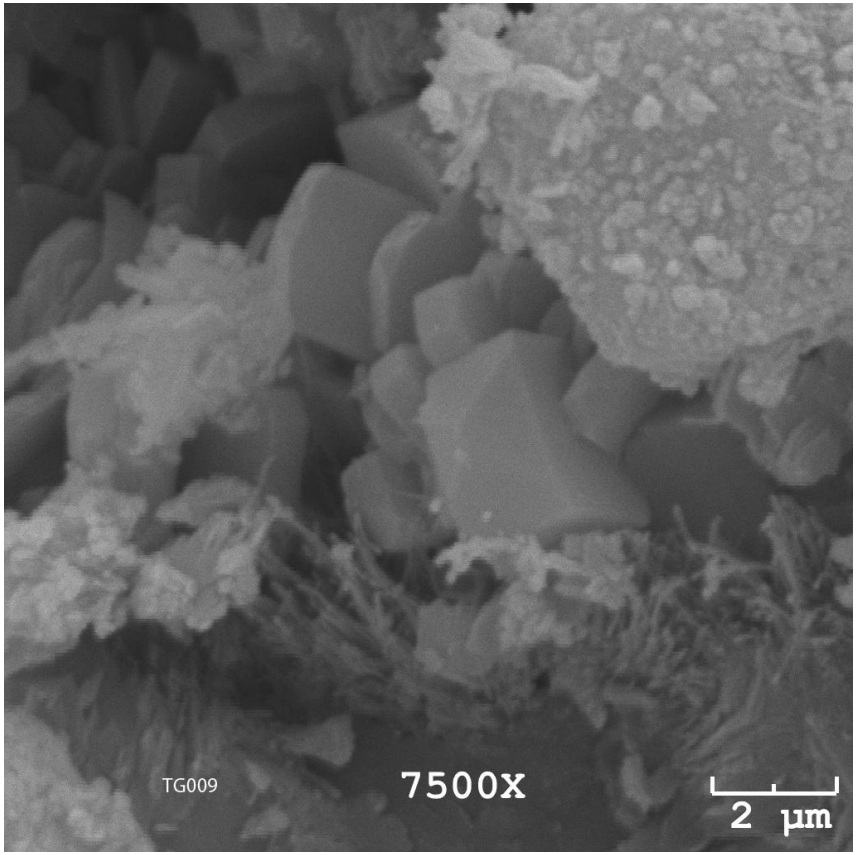
- **Role of Zeolites**

1. Zeolites added to cement as pozzolan help create a light weight slurry
2. Increases drying time and hence increases the strength
3. Increases the strength of cement till 10% bwoc and decreases thereafter, though decrease is not significant
4. Improves resistance to chloride permeability, alkali-sulphate reactions and acid/ sulphate attacks

SEM Analysis

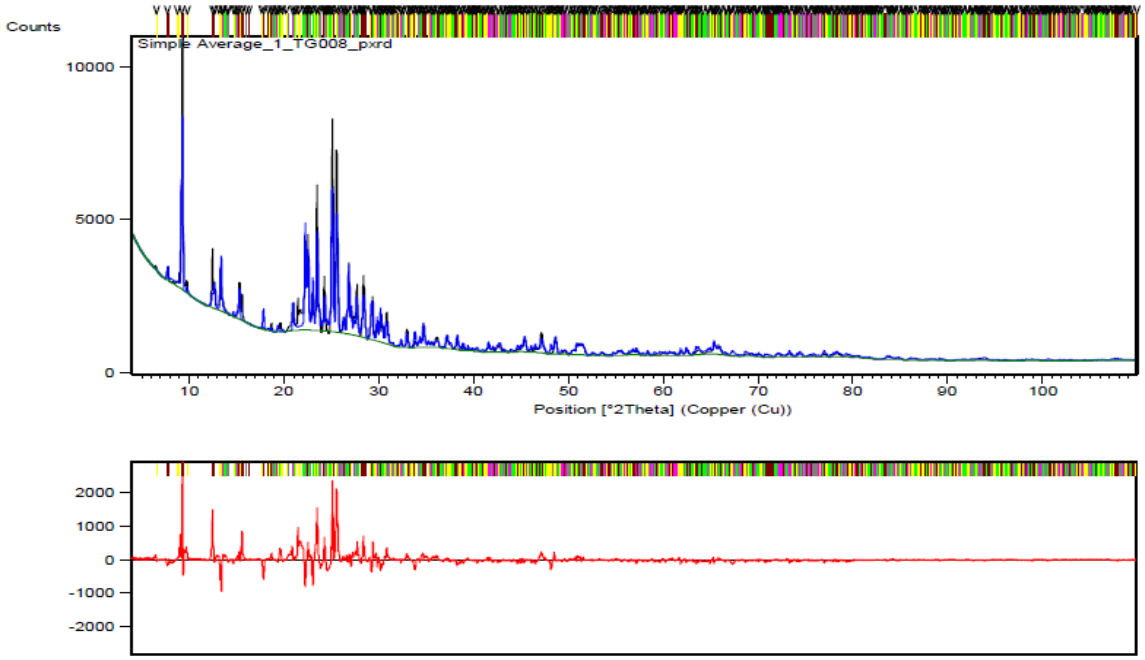
Objective – Find the types and percentages of zeolite present.

1. TG007 Ferrierite (crushed)
2. TG008 Ferrierite (crusher fines)
3. TG009 MH Clinoptilolite (crushed)
4. TG011 MH Clinoptilolite (crusher fines)
5. TG017 Chabazite (crushed)
6. TG018 Chabazite (crusher fines)
7. TG014 Analcime (crushed)
8. TG015 Analcime Calcined (coarse crush)



XRD and XRF Analysis

- XRD and XRF analysis gave refined and more accurate composition of the samples than SEM analysis
- XRF is used to screen some of the components so as to augment the XRD results



Zeolite Preparation

- Following XRD, XRF and SEM studies three hundred pound splits of the bulk samples were shipped to CCE Technologies for preparation.
- Micronized using Jet Mill Technology.
- Prepared sizes with 80% in range:
  - 5 micron
  - 10 micron
  - 44 micron
- Alternate 44 micron prepared using Collider Mill Technology

Project Management/Coordination

- Project Objectives (Targets) have been formulated as specific performance characteristics that are necessary for a high temperature cement.
- Each of the Objectives requires measurable data that can be evaluated to determine the success or failure of a particular cement blend.
- Clear and concise performance characteristics provide a systematic method for initial screening, second stage development and ultimately for the final stage of cement development.

Variances

Subawardee ThermaSource Cementing unable to participate.

Corrective Action

- Scope of work shifted to the University of Alaska Fairbanks.
- Halliburton Energy Services providing Graduate Student Training.

Data Sharing

- Data Types
  - Digital and Hard Copy Jet Mill Particle Size Distribution
  - Digital and Hard Copy Collider Mill Particle Size Distribution
  - Digital and Hard Copy SEM / XRD and XRF Images / Graphs
  - Digital and Hard Copy Cement Particle Size Distribution
  - Digital and Hard Copy Initial Cement Blend Properties
  - Digital and Hard Copy Blend Formulation Trials
- Data Management
  - On-site hard drive / backup
  - On-site files
  - Established ftp secure site for data sharing
  - DOE Geothermal Data Repository questionnaire submitted

Collaborations

- **Subawardee**
  - Petroleum Development Laboratory, University of Alaska Fairbanks
- **Industry Support**
  - Halliburton Energy Services
  - Texas Lehigh Cement, Texas
  - Lehigh Cement, California
  - Dykerhoff AG, Germany
  - Ormat Technologies, Nevada
  - Chena Hot Springs Resort, Alaska
- **International Inquires**
  - Australia
  - New Zealand
- **American Recovery and Reinvestment Act Jobs**
  - 10.55 Jobs Created (Limited at current research stage of the project.)

Future Directions

- FY 2011 Project Activities
  - Complete Initial Screening of Cement Formulations
  - Modification of Second Stage Development Based on Initial Screening Results
  - Begin Second Stage Cement Development
  - Continue Research on Additives and Methods

- Milestones / Go/No-Go Decision Points
  - Project continues if at least 3 cement formulations pass Initial Screening.
  - Project continues if at least 2 cement formulations pass Second Stage Development as candidates for field testing.

Summary

- The project is in keeping with the stated goals of the Geothermal Technologies Program under the Multi-Year Research, Development, and Demonstration plan.
- Successful completion of the project will result in the development of a cementing solution for geothermal wells that is cost effective as well as logistically simple.

FY2010 Tasks Completed	FY2011 Tasks Scheduled
Literature / Practices and Constraints	Initial Cement Blend Screening
Review of Well Failure Mechanisms	Modify Second Stage (Initial Results)
Zeolite Bulk Sample Acquisition	Second Stage Cement Development
Zeolite Confirmation XRD/XRF/SEM	Research on Blend Additives
Micronized Zeolite Initial Formulations	Begin Tests Second Stage Cement
Protocol Initial Cement Screening	